Editorial & Letters

EDITORIAL

A Third Technological Revolution

Changes that will have effects comparable to those of the Industrial Revolution and the computer-based revolution are now beginning. The next great era, a genomics revolution, is in an early phase. Thus far, the pharmacological potentials of genomics have been emphasized, but the greatest ultimate global impact of genomics will result from manipulation of the DNA of plants. Ultimately, the world will obtain most of its food, fuel, fiber, chemical feedstocks, and some of its pharmaceuticals from genetically altered vegetation and trees. Until recently, comparatively little research has been devoted to changing plant genomes. Now, major companies including Dow Chemical, DuPont, Monsanto, Novartis, Pioneer Hi-Bred, and AgrEvo are spending billions of dollars annually on genetic engineering and on acquiring stakes in genome-oriented companies. For example, DuPont has obtained a 20% stake in Pioneer Hi-Bred, the major corn breeder and distributor. Calgene is now owned by Monsanto, and Mycogen is controlled by Dow.

During the initial years of the plant genomics revolution, major companies conducted research to achieve resistance to their proprietary herbicides, and they have succeeded. Resistance to some important pests has also been achieved. Genetically altered seeds are now being produced on an increasingly large scale. For example, Monsanto has genetically altered soybeans, cotton, canola, potatoes, corn, and other plants. The research for these products was financed and in part motivated by sales of Roundup, a highly profitable herbicide.

Seeds of plants resistant to Roundup were developed in the mid-1980s, and their creation has helped agriculture. Weed control is achieved with much less cultivation, less erosion, and less compaction of soil. Since then, seed varieties well adapted to many different locations have been successfully field tested.

Federal regulations for genetically altered plants require complex, costly, and time-consuming testing. The crops have been repeatedly analyzed chemically, and their safety for consumption by humans and farm animals has been established. After federal approval, sales of seeds can occur and then expand rapidly. A case in point is Roundup Ready soybean seeds. Monsanto introduced the seeds commercially in 1996, with 1 million acres being planted. In 1997, seeds were sown on 9 million acres, and in 1998, they will be sown on 20 million acres. Other companies are now producing and selling genetically altered seeds.

The emphasis of industrial genomics research and development is shifting to other areas, including improvement of the quality of fats in foods. Previously, most of the feedstock for margarine was low-melting, highly unsaturated oils derived from soybeans. These were subjected to industrial hydrogenation. The resultant product contained trans-fatty acids, which are medically deleterious. Using genomics, safer fats are being developed and produced by DuPont, Calgene, and other companies. The fats are more nutritious for humans and monogastric animals. Other efforts are being made to improve the nutritional value of plant proteins and the nature and content of plant carbohydrates. Ultimately, the level of natural poisons in foods will be minimized.

Through genomics, the composition of fats and other components of seeds can easily be drastically manipulated. Applications for such substances are increasingly being found by industry. The results of recent research (*Science*, 4 July 1997) suggest that modified root crops will ultimately supply commercially useful amounts of oil. Significant yields of a biodegradable plastic have also been attained by altering the genome of *Arabidopsis*. Efforts to commercialize this achievement are under way. The synthetic capabilities of genetically altered plants as a source of pharmaceuticals are also being explored.

The practical effects of the genomics revolution will only be partially manifested during the next decade. During that time, the genomes of microbes, plants, and mammals will be sequenced, and much will be learned about the functions of genes and the means by which they are controlled. Today, humans employ the capabilities of only a few plants. A major challenge is to explore the opportunities inherent in some of the hundreds of thousands of them.

Philip H. Abelson

LETTERS

Calculus and coral

The mathematics of math and science literacy are clarified, as is the nature of a study of calculus reform carried out at the National Science Foundation. A model of fishery and coral reef management is critiqued and defended. And coral reef researchers propose that damage thought to have been caused by a newly discovered "wasting disease" has actually been caused by parrotfish bites (above, fish biting coral).

R. BRUCKNER

Calculus Reform

We are writing to correct the representation of our views in the Random Samples item "Math whizzes spurn reformed calc" (20 Feb., p. 1137). The quotes printed for each of us were correct, but the context in which our comments were made is not included. And the negative tone of the item's title does not accurately reflect the complete picture, but is an example of what can be used to divide the mathematics community on this very important issue. The work of one of us (S.L.G.) at the National Science Foundation (which did not include the alleged survey of 150 professors) is intended to promote discussions among mathematicians by providing information on the current status of the reform efforts. The study includes many positive outcomes (such as improvements in course completion rates and student attitudes toward mathematics), as well as areas for improvement, such the one referred to in the article. However, the work is intentionally structured so as to not pass judgment on the value of reform, and any implication to the contrary is unfounded.

Another of us (D.J.L.) notes that both parties in the dispute [about calculus reform] have probably gone overboard. It is true that the early new calculus texts did need more rigor; however, students do need to learn modeling, which the old texts and approaches avoid. And another of us (D.H.-H.) believes that, to teach rigor effectively, you need to make sure that students have a geometric and intuitive idea of the concepts first, and can describe them verbally, before doing them rigorously. Most students (but